A Novel Codeword Assignment Strategy based on MLMW-OOCs for Fiber Fault Monitoring in Large Capacity PON

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Abstract: A novel codeword assignment strategy based on MLMW-OOCs is proposed for large capacity PON monitoring. The results show that it realizes the shorter code length and smaller correlation distance, and better SIR performance than 2D-OOCs.
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1. Introduction

With the huge amount of Fiber to the Home/Building (FTTH/B) deploying massively, the research for cost-effective, in-service, and practical optical layer performance monitoring mechanisms are becoming increasing important for network operators [1]. Several optical coding monitoring schemes based on one dimensional periodic codes (1D-PCs) and two dimensional optical orthogonal codes (2D-OOCs) have been proposed, which is effective on point-to-multipoint networks like a PON and significantly increases the scalability with low cost [1-2]. However, the code length and correlation distance of the 1D-PCs and 2D-OOCs increases rapidly as the increase of network size. Moreover, both 1D-PCs and 2D-OOCs are equal-length codes which are assigned randomly to each user without the consideration of the user geographical distribution, hence there exist severe interference, especially when user separation length (i.e., the length of DDFs) is close to each other.

To improve codeword capacity (i.e., the number of users) as well as reduce the effect of interference, we propose a novel codeword assignment strategy based on multiple-length multiple-wavelength optical orthogonal codes (MLMW-OOCs) by considering the relationship between interference and user separation length. Our proposed scheme can support the monitoring of large capacity PON with shorter code length and smaller correlation distance. In addition, the signal-to-interference ratio (SIR) of MLMW-OOCs performs better than 2D-OOCs coding scheme.

2. MLMW-OOCs assignment strategy and the definition of SIR

Fig. 1(a) illustrates the principle of the MLMW-OOCs optical coding scheme for fiber link identification in a PON. At OLT side, the detecting pulse generator transmit a U-band detecting pulse with the power of P_S and the duration of T_C to all subscribers. Then it is encoded and reflected back to OLT by passive MLMW-OOCs encoders (multi-FBG) placed at the edge of the DDFs. In monitoring system at OLT side, the decoding signal (autocorrelation peak) of each link can be achieved by the array of MLMW-OOCs decoder to identify each subscriber from the other.

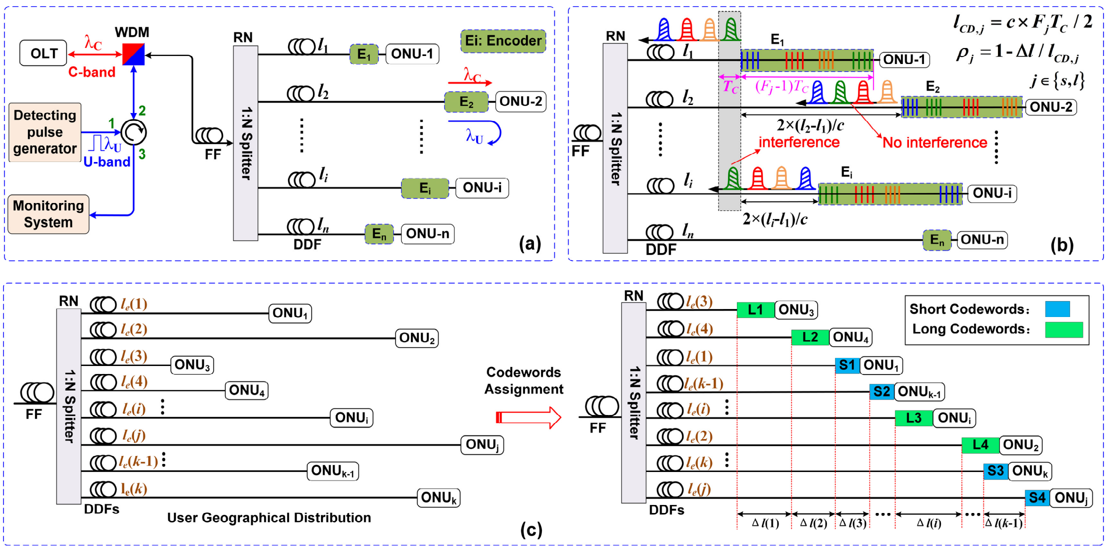

Fig. 1 (a) Principle of the MLMW-OOCs coding monitoring system; (b) Principle of the correlation distance and partial interference between two codewords; (c) user geographical distribution and MLMW-OOCs assignment.

The MLMW-OOCs are represented by a family of ($m \times F$, w, λ_a, λ_c, D), where m is the number of wavelengths, F is a set of code length, w is code weight, λ_a is a set of autocorrelation constraints, λ_c is a set of cross-correlation constraints, and D is a set of codeword-cardinality distributions [3]. We assume a set of code length is $F=\{F_s, F_l\}$, among which F_s is the code length of short codewords and F_l is the length of long codewords, and the number of short and long codewords is Φ_s and Φ_l, the code cardinality of MLMW-OOCs is $\Phi = \Phi_s + \Phi_l$ and $D = \{\Phi_s/\Phi, \Phi_l/\Phi\}$. For instance, we can construct an set of (4×{25, 425}, 4, {1, 1}, {1, 1, 1}, {16/288, 272/288}) according to an algebraic construction algorithm which has been proposed in [3], and assign these double-length codewords for PON link monitoring. As illustrated in Fig. 1(b), when the distance difference ($l_2 - l_1$) between the target encoder E_1 and another encoder E_2 is larger than the value $c\times FT_C/2$, the decoded sub-pulses signal reflected by the E_2 cannot overlap the target signal and hence there is no interference components. Inversely, when the distance difference $\Delta l = |l_i - l_1|$ between E_i and E_1 is smaller than the value $c\times FT_C/2$, the sub-pulses will partially overlap and contribute to interference to each other. Therefore, we define the correlation distance is $l_{CD,j} = c\times F_jT_C/2$, $j\in\{s, l\}$, considering short (s) and long (l) codewords respectively [4]. In Fig. 1(c), with the consideration of user geographical distribution, we propose a novel codewords assignment strategy based on the double-length MLMW-OOCs. The main idea behind the strategy is to prioritize short codewords to those users adjacent to each other.

The procedure of the assignment strategy is as follows:

1) Construct double-length MLMW-OOCs codewords according to [3]. We assume the network size (the number of users) is K and the number of assigned short and long codewords in the monitoring system is K_s and K_l, and the constraint conditions is $K= K_s + K_l$, , $K \le \Phi$, $K_s \le \Phi_s$ and $K_l \le \Phi_l$, respectively. Let l_e be the maximum user separation length (i.e. maximum length of DDFs). Each length of the DDFs is uniform distribution in [0, l_e].
2) Set $\{l_e(1), l_e(2), l_e(3), l_e(4),..., l_e(i), l_e(j),..., l_e(k\text{-}1), l_e(k)\}$ to the length of DDFs, respectively; Sort the user separation length in an ascending order, such as $\{ l_e(3), l_e(4), l_e(1), l_e(k\text{-}1), ..., l_e(i), l_e(2), ..., l_e(k), l_e(j)\}$.
3) Calculate the distance difference of two adjacent length of DDFs as: $\Delta l(1) = l_e(3) - l_e(4)$, $\Delta l(2) = l_e(4) - l_e(1)$, $\Delta l(3) = l_e(1) - l_e(k-1)$, $\ldots$ $\Delta l(i) = l_e(i) - l_e(2)$, $\ldots$ $\Delta l(k-1) = l_e(k) - l_e(j)$.
4) Sort these distance differences Δl in an ascending order: $\Delta l(3) \le \Delta l(k-1) \le \cdots \le \Delta l(2) \le \Delta l(1) \le \Delta l(i) \le \cdots$.
5) According to the Δl sorting above, the pair of users with the minimum Δl will be given priority in allocation of the short codewords, and then the other closer users pair are also assigned sequentially until all short codewords are assigned, after which the long codewords begin to be assigned for remaining users.

In our pervious works [4], the system mathematical model with the equal-length 2D-OOCs has been established. Using the above model, the desired signal (i.e., autocorrelation peak of the same codeword) can be expressed as

$$\mu_{sig,j} = G\alpha_{Total}\xi_i e^{-2\alpha_a l_{i,j}} wP_S,\ j\in\{s,l\}. \tag{1}$$

where G is the gain of the APD, α_{Total} denotes the total loss including the circulator, splitter, connectors, and so forth, in the monitoring system. $\xi_i=\{0,1\}$ means different status of the target DDF$_i$. Specifically, when DDF$_i$ is broken, $\xi_i=$ 0; when DDF$_i$ is healthy, $\xi_i= 0$. The term $e^{-2\alpha_a l_{i,j}}$ is an attenuation model for the FF and DDFs [4].

Regarding the interference components, we considered two specific cases. 1) When the target codeword is short, the interfering codewords can be short or long. The interference signal consists of two parts, which can be written as

$$\mu_{\text{int},s} = G\alpha_{Total}\xi_k\rho_s\left[\left(K_s-1\right)q_s e^{-2\alpha_a l_{k,s}} + K_l q_{s,l} e^{-2\alpha_a l_{k,l}}\right]P_S. \tag{2}$$

2) When the target codeword is long, the interfering codewords can be short or long. Thus the interference signal can be also expressed as

$$\mu_{\text{int},l} = G\alpha_{Total}\xi_k\rho_l\left[\left(K_l-1\right)q_l e^{-2\alpha_a l_{k,l}} + K_s q_{l,s} e^{-2\alpha_a l_{k,s}}\right]P_S. \tag{3}$$

where q_s, q_l, $q_{s,l}$, and $q_{l,s}$ is the one-hit probability between the target and interfering (short or long) codewords in four cases, respectively. These probabilities can be obtained according to [3]. ρ_s and ρ_l is the partial interference ratio between the target (short or long) codeword and the interfering codeword, i.e., $\rho_j = 1 - \Delta l / l_{CD,j}$, $j\in\{s, l\}$.

Then, the SIR$_j$ for short and long codeword is defined to be the square of the expectation of desired signal power divided by the expectation of interference signal power, respectively

$$\text{SIR}_j \triangleq \left[E(\mu_{sig,j})/E(\mu_{\text{int},j})\right]^2,\ j\in\{s,l\}. \tag{4}$$

From the above, we can get the total SIR of the monitoring system as follow

$$\text{SIR} = \left(\frac{K_s}{K}\right)\cdot\text{SIR}_s + \left(\frac{K_l}{K}\right)\cdot\text{SIR}_l,\ \left(K = K_s + K_l\right). \tag{5}$$

3. Performance evaluation

In the following simulation, we consider the transmitted pulse power P_S = 4 dBm in order not to induce fiber nonlinearity, the detecting pulse width T_C is 1 ns. An APD with gain of 100 is used and total loss is 5 dB for the circulator, splitter, connectors, etc. We also consider a 20 km FF link between the OLT and RN.

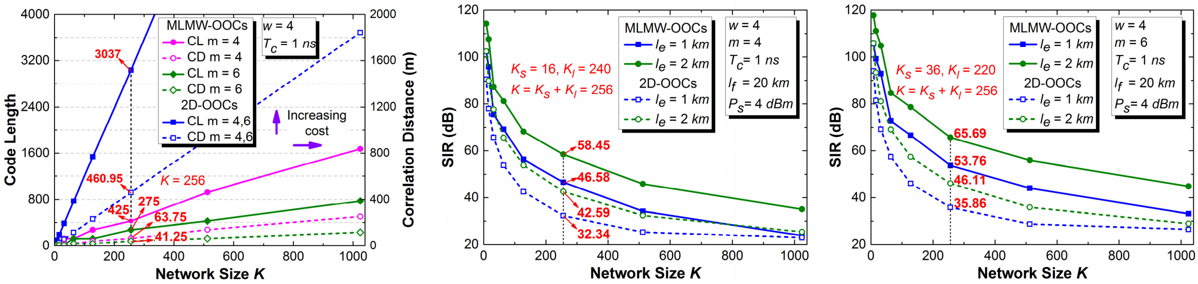

Fig. 2 (a) Code length and correlation distance versus network size K for MLMW-OOCs and 2D-OOCs with different wavelengths m; (b) SIR versus network size K for MLMW-OOCs and 2D-OOCs with different client separation length l_e, m = 4; and (c) m = 6.

In Fig. 2(a), we can observe that for different number of wavelengths m, the code length (CL) and correlation distance (CD) increase linearly as the network size K varies for both MLMW-OOCs and 2D-OOCs coding schemes. However, the CL and CD of MLMW-OOCs are significantly smaller than that of the 2D-OOCs. It means that the encoder length of MLMW-OOCs coding scheme is shorter than that of the 2D-OOCs. For K=256, the CL of 2D-OOCs is 3037, which is much longer than that of the MLMW-OOCs. The CD of MLMW-OOCs is 63.75 m (m = 4) and remarkably smaller than 460.95 m of 2D-OOCs. For a large capacity PON, the distance of several fiber links may be close to each other and the distance difference Δl may be also small. Therefore, the new coding monitoring scheme based on MLMW-OOCs can support high capacity PONs with small CD to reduce the interference signal and also with shorter CL to reduce encoder cost.

As mentioned in Eq. (5), we plot the SIR curves for MLMW-OOCs and 2D-OOCs coding schemes with m = 4 with different network size K and different client separation length l_e as shown in Fig. 2(b), where solid and dash-dotted curves represent MLMW-OOCs and 2D-OOCs coding scheme, respectively. As a whole, the performance of SIR worsens as the network size K increases due to the increase of the interference. In Fig. 2(b), for K=256, when l_e = 1 km, we can find that the SIR of MLMW-OOCs is 46.58 dB, larger than 32.34 dB of 2D-OOCs; when l_e = 2 km, the SIR of MLMW-OOCs is 58.45 dB, also larger than 42.59dB of 2D-OOCs. Hence, we conclude that the SIR of MLMW-OOCs always perform better than 2D-OOCs under the different client separation length l_e. In addition, for a fixed K, as the client separation length l_e increases from 1 km to 2 km, the SIR performances of both the MLMW-OOCs and the 2D-OOCs can improve from 46.58 dB to 58.45 dB and from 32.34 dB to 42.59 dB respectively. It is because that the distance difference Δl of two adjacent users increases leading to the decrease of interference signal. Similar to Fig. 2(b), using the same simulation conditions, we give out the SIR versus network size K for m = 6 in Fig. 2(c). For a given network size K = 256, when wavelengths m is 6, the number of short codewords K_s is 36, the SIR increases as assigned K_s (the number of short codewords) increases. Moreover, as m increases, the improvement of SIR of the MLMW-OOCs coding system is obviously larger than that of the 2D-OOCs. Therefore, we can conclude from above figures that the SIR of MLMW-OOCs scheme performs better than 2D-OOCs scheme.

4. Conclusion

A novel codeword assignment strategy based on MLMW-OOCs for large capacity PON monitoring is proposed to reduce the effect of interference as well as improve the performance of monitoring system. Simulation studies show that compared to 2D-OOCs coding scheme, our proposed MLMW-OOCs scheme can support monitoring large capacity PONs with shorter code length, smaller correlation distance to reduce cost, and better SIR performance.

5. Acknowledgements

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